DIFFICULTIES WITH LARGE BUBBLE CHAMBERS

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ABSTRACT

In this report I consider various difficulties associated with large bubble chambers and in particular the 25-foot bubble chamber as proposed by the BNL group. The classes of problems considered are:

1. Optical problems associated with the large depth of field.
2. Transient effects produced by the expansion systems. Effect of delay times (from the propagation of the expansion wave) in the expansion system.
3. Mechanical stability.

The conclusions are:

1. The bubble size required for visibility will be large, about 1 mm. This in turn means the growth time will necessarily be large.
2. The transient effects are large and must be carefully considered. The focusing properties of a sphere are such that parts of the chamber may be grossly over expanded. This might be a disaster in that it would short-circuit the expansion system.
3. The delay times will probably produce large transient stresses in the chamber body.
4. The position errors used in the calculations of Trilling and Derrick are probably considerably too small.

I. INTRODUCTION

Bubble chambers are relatively simple and forgiving devices. In essence, all that one needs to do is rapidly to lower the pressure in hot liquid, and the liquid becomes radiation sensitive. Compared to a cloud chamber, with all its associated folklore, the bubble chamber seems remarkably simple.

Very large bubble chambers (super chambers) are relatively simple devices also. The difficulties come in generalizing from small to large in three respects:

1. Strength of materials (particularly glass)

2. Speed of sound effects (a homogeneous pressure is desirable)
3. Optical problems (particularly depth of focus).

The author was one of the first to propose a super bubble chamber of the ANL or BNL type. The concept is dominated by the difficulties associated with large glass windows. Such windows are fragile and expensive and must be handled with extreme care. They limit the turn-around time because of the rather slow cooling or warming rates that can be tolerated by the glass. Consequently large chambers of this type now under discussion have small ports, with fish-eye optics.

The shape of the "25-foot" is dictated by the strength of material. A sphere is a stable, calculable structure. (The wall thickness looks too thin to me for a dynamic situation although it's clearly sufficient for a static situation.)

II. OPTICS

My objections to the present design almost always have as their root the optical considerations. The ultimate test of any chamber is one's ability to get useful pictures out of it. Let's compare the optical situation in a coventional chamber and the proposed system, as shown in Fig. 1; p is about 2 m, d is 0.5 m. The deviation δp from the plane of best focus is ± 0.25 m; thus $\delta p/p \simeq 1/8$.

Diffraction effects and the film nonlinearity also help. In the plane of best focus the bubble produces a bright spot on the film, the angular radius of which is $\theta = 1.2\ \lambda/a$. The radius R of the bubble image on the film is then (see Fig. 2)

$$R = 1.2\ \lambda(q/a)$$

$$\approx 1.2\ \lambda(F),$$

where a = diameter of lens aperture, q = image distance, and F = F stop. As shown in Fig. 9 of the 25-Ft Proposal (BNL-12400), as we go out of focus the relative intensity at the second maximum rises, but one can discriminate this out by means of the film. Thus one finds the bubble diameter as a function of δp looking as shown in Fig. 3. The behavior of the image size is quite different from what would be expected from geometrical optics.

The discussion here and in the BNL proposal speaks in terms of bright sources--hence dark-field optics. The proposal is for bright-field, Scotchlite optics. These two systems, bright and dark, are different. Babinet's principle is of considerable help in that it tells you that the shape of the diffraction pattern from either system is the same. This is probably only approximately true for bubbles. In fact the images of bubbles in a bright-field system are practically two times larger than in a dark-field system. The delay time between beam pulse and light flash tends to be longer for a bright-field system. This means that the bubbles must grow larger in order to achieve sufficient contrast on the film. In the SLAC chamber the bubble diameter space is ~ 300μ. This is perhaps a factor of two greater than the diffraction limit. The point of this discussion is that current bright-field systems use large bubbles in order to achieve useful contrast.

We continue our discussion of the super chamber system. In a conventional system we usually neglect the effect of the variation of the camera to object distance. This is a large effect in the case of the super chambers. The amount of light (from a bright source) incident on the lens is of course given by $I_0(\theta) \cdot A/r^2$, where A = area of the lens and r = object-to-lens distance. If we consider a span of r over a factor of four we have an intensity variation of 16 from near to far points. This would be a difficult situation even with dark-field optics, but it seems an order of magnitude more difficult with bright-field optics. The reason may be seen in Fig. 4. The width of each pattern is supposed to be the same. The signal-to-noise ratio varies widely as we go from near to far point. It will be difficult to record these patterns on one piece of film. A possible solution might be to run the bubble size to the non-diffractive domain at the best-focus (object) plane. The bubble diameter would have to be 0.5 - 1.0 mm. With conventional bubble chambers this would mean growth times of at least 5 - 6 msec. This is a frighteningly long time in terms of bubble drift (gravitational drift might be about 50μ). The requirement of a long growth time puts an additional strain on the expansion system.

The demagnification proposed produces trouble because of the film resolution. A resolution of 5μ is quoted (W. F. Fry says that under laboratory conditions he was not able to achieve better than 8 - 10μ). A bubble image size of 14μ as in the BNL proposal is dangerously close to the film limit. In fact it means that the contrast is reduced by the graininess of the film. Again this situation could be remedied by using larger bubbles.

There is no discussion in the proposal of optical aberrations, such as coma, for the large angle rays. Any such effect as this or chromatic aberration will also tend to destroy the contrast. Again it would be necessary to have large bubbles in order to produce the necessary contrast.

The distortions produced by the optical relay system are not discussed. W. F. Fry claims that the relay system can be made better than the basic wide-angle lenses. It would be useful to have a quantitative discussion of this.

It seems to me that the optical situation demands very large bubbles with rather long growth times. This puts very stringent demands on the expansion system.

III. EXPANSION SYSTEM

It is perhaps worthwhile to compare the problems of expanding a super and a conventional bubble chamber.

Spurious Boiling

The super chamber, because of its larger volume-to-surface ratio, should be easier to expand. This advantage is partially offset by the longer expansion times.

Velocity of Sound Effect

In a conventional chamber it is probably possible to see some ringing effects in the pressure trace. With the super chamber the velocity effects are very large. The time required for a pressure front to propagate across the chamber is 5 milliseconds. There are differences of distances from the center to the extremes of the chamber of the order of 2 or 3 meters. This means that there will be sizeable pressure differances between parts of the chamber. With an expansion time of 20 msec and a pressure drop of 40 psi, $dp/dt = 2$ psi/msec. Thus one would expect to find Δp's of 2 - 4 psi from center to the side of the chamber, and Δp of 8 psi from top to bottom in the course of the expansion. If the bubble density is to be uniform then the chamber should be given 2 - 3 msec to equilibrate. The spherical shape of the chamber can also produce peculiar reflection effects (see Fig. 5). The sources in the expansion process are a pair of concentric rings. The source rings will be imaged along a vertical axis through the center of the chamber. It is conceivable that the chamber might be overexpanded in this region with a resulting frothy region. Such a situation might well be disastrous since a region of froth would short circuit the expansion.

I believe that there is a critical velocity of the piston which should not be exceeded or at least should serve as a scale. Consider the expansion of a cylinder of liquid (see Fig. 6). Suppose the pressure on the surface is released; the question is, how fast will the surface move upward? In order for the liquid to be fully expanded the wavefront must propagate to the bottom of the cylinder. When that has happened the liquid will be fully expanded. In the case of the bubble chamber the modules of elasticity is such that a 0.5% expansion is required. Then in a time ℓ/v_s the liquid surface will have moved $0.005\ \ell$. Thus the average velocity is 5 meters/second or 16 ft/sec. The proposal calls for a velocity of 32 ft/sec for the piston. This probably means that the liquid will be ruptured at the piston. This means that the expansion will be inefficient, hence will produce an increased heat load. This difficulty is produced by the relatively small size of the piston and the large stroke. It should be noted that the Argonne super chamber's expansion seems far more satisfactory, in that the size of the piston is larger. The velocity in that system will be approximately 5 ft/sec which is well under the critical velocity.

The baffles in the system will also produce some difficulties. It is not clear what velocity pattern will be produced by the baffles. One knows that $P_L + 1/2\ \rho\nu^2 = \text{const.}$, if one considers the hydrogen incompressible. It may be that appreciable pressure drops will be produced at sharp edges--hence boiling. A liquid velocity of 100 ft/sec would produce a pressure drop of 1/3 atm.

The baffles seem to me to have an unknown but probably small effect. They produce an impedance to the expansion in that they produce a large change of direction of flow. The dynamic pressure drop is the order of $\rho(\Delta\nu)^2$. This in general will be less than one psi unless there are locally very high velocities ($\geq$ 100 ft/sec). There will be very large forces acting on the baffler. I have not worried about effects of viscosity which will make the baffler effects somewhat worse.

The summary of my feelings about the expansion systems is as follows. Optical considerations require very high performance from the expansion system--long growth time and large pressure drop. The relatively small piston is certainly not an optimum system in that the velocities seem high compared to my scale velocity of 16 ft/sec. This will probably mean a somewhat inefficient expansion. This in turn means locally high velocities and a larger heat input to the chamber. Bubbling will make the optics bad in that heat striae, if they are close to the bubbles, will further destroy the optical contrast which is the prime necessity. If the striae are a sizeable distance from the lens then the light rays are multiply scattered which will hurt precision in reconstruction. The effect due to the drift of the bubbles during the rather long growth time could be a far larger effect (errors of the order of several millimeters). This is because there are locally very high velocities produced by the expansion system.

The velocity of sound effects and focusing effects will probably produce some variation of track density across the chamber. The focusing effects must be considered further as they may be disastrous. The heat input in the expansion of the chamber will be localized in the center of the chamber and will probably add to the nonuniformity of the tracks.

Lastly, I would note that the 7-ft "model" is not a terribly good model for the 25-ft expansion system. The bad effects depend on details of shape, and vary as ν^2.

IV. STRUCTURAL PROBLEMS

As noted in the section on the expansion system, there are very sizeable transient pressure differences between parts of the chamber during expansion. I noted a 10,000 lb net upward force on the top of the chamber acting over a period of 10-20 msec.

This is certainly a small force compared to the static vapor pressure forces. Steel shells are very strong in tension and spheres are particularly stable. The static deflections for a sphere of 20 ft are small: about 10 mils in radius. Shells are much more susceptible to deflections which do not change the surface area since in such cases the restoring moments are quite weak. Again it should be noted that a sphere is the most stable shape, but the shape of the 25-ft chamber is really more like a football. Thus I believe that the chamber should be very carefully modeled in the dynamic situation of expansions. I would believe that the structure should probably be stiffened with ribs. W. F. Fry commented that in the MURA model chamber these dynamic stresses were quite large. That chamber was cylindrical in shape (2 m long, 1/2 m diam) which is a somewhat more unstable shape.

V. SUMMARY

The optical problems associated with this chamber are very difficult. They can be surmounted in part by large bubble-growth times. This in turn puts additional demands on the expansion system which is one of the most difficult aspects of the chamber. The transient effects, because of the size of the chamber, are important and must be carefully considered. The dynamic structural effects should probably be modeled. It seems to me that as a result of these considerations the errors used in the calculations of Derrick[1] and Trilling[2] are too small perhaps by an order of magnitude.

REFERENCES

[1] M. Derrick and R. Kraemer, Parameters of a Large Bubble Chamber: Scaling of Momentum and Angle Errors, National Accelerator Laboratory 1968 Summer Study Report A.1-68-35, Vol. I. p. 1.

[2] G. Trilling, Strong Interactions in the 25-Ft Bubble Chamber, National Accelerator Laboratory 1968 Summer Study Report A.1-68-86, Vol. I, p. 115.

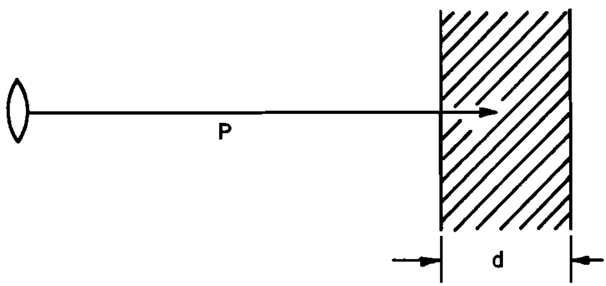

Fig. 1. Optics of a bubble chamber: p is the lens to object-plane distance, d is the depth of field.

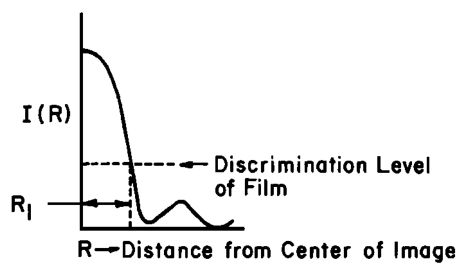

Fig. 2. Intensity distribution in a (diffraction-limited) bubble image.

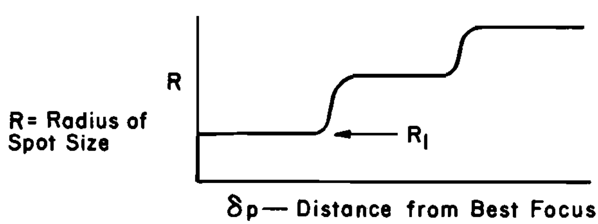

Fig. 3. Variation of apparent bubble radius with distance from object plane.

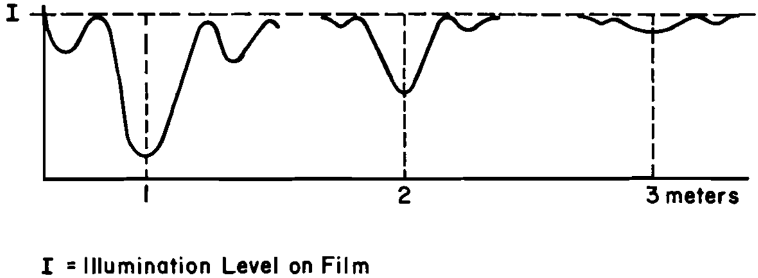

Fig. 4. Effect of intensity variation with dark field illumination.

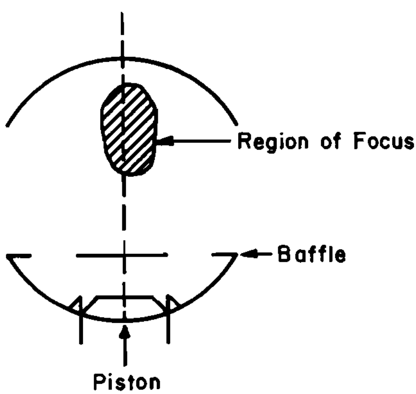

Fig. 5. Focusing of a pressure pulse by reflection from a spherical surface.

Fig. 6. Model of chamber volume.